

AMENDMENTS TO THE CLAIMS

Please amend Claims 1, 3, 4, 15, 20, 25, 27, 28, 30, 36, 43, 44, 46, 49, 50, 67, 69, 78, 81-83, 91, and 94. Please cancel Claim 53. Please add new Claims 95-100.

1. (Currently Amended) A method for producing a group IB-IIIa-VIA quaternary or higher alloy semiconductor film, the method comprising the steps of:

(i) providing a metal film comprising a mixture of group IB and group IIIa metals;

(ii) heat treating the metal film in the presence of a source of a first group VIA element, $[(Q)]$ said first group VIA element being hereinafter referred to as $VIA_1[(Q)]$, under such conditions to form that the reaction between the group VIA_1 element and the metals of the mixture of the metal film is incomplete and a first film is formed comprising a mixture of at least one binary alloy selected from the group consisting of a group IB- VIA_1 alloy and a group IIIa- VIA_1 alloy; and at least one group IB-IIIa- VIA_1 ternary alloy,

(iii) heat treating the first film in the presence of a source of a second group $[(VIA_2)]$ VIA element, $[(Q)]$ said second group VIA element being hereinafter referred to as $VIA_2[(Q)]$, under conditions to convert the first film of step (ii) into a second film comprising at least one alloy selected from the group consisting of a group IB- VIA_1 - VIA_2 alloy and a group IIIa- VIA_1 - VIA_2 alloy; and the at least one group IB-IIIa- VIA_1 ternary alloy of step (ii); and

(iv) heat treating the second film of step ((iii)) to form a group IB-IIIa-VIA quaternary or higher alloy semiconductor film.

2. (Original) The method according to claim 1, wherein the mixture of the first film of step (ii) is a stable mixture such that the molar ratio of all the group IB- VIA_1 and/or group IIIa- VIA_1 alloys to all the at least one group IB-IIIa- VIA_1 ternary alloy remains substantially constant.

3. (Currently Amended) The method according to claim 1, wherein the metal film of step (i) is provided on a substrate ~~optionally coated with a metal layer~~.

4. (Currently Amended) The method according to claim 3, wherein the substrate is coated with a Mo metal layer is a Mo layer.

5. (Original) The method according to claim 1, wherein the metal film of step (i) comprises a mixture of metals selected from the group consisting of Cu, In and Ga.

6. (Original) The method according to claim 5, wherein the metal film of step (i) is a Cu—In—Ga alloy metal film.

7. (Original) The method according to claim 5, wherein the metal film is a Cu—In alloy metal film.

8. (Original) The method according to claim 1, wherein the group VIA₁ element is Se.

9. (Original) The method according to claim 1, wherein a source of the group VIA₁ element is a gaseous mixture of H₂Se and at least one inert gas.

10. (Original) The method according to claim 9, wherein the inert gas is Ar.

11. (Original) The method according to claim 9, wherein the molar concentration of Se relative to the at least one inert gas is from 0.01 to 15 molar percent.

12. (Original) The method according to claim 11, wherein the molar concentration of Se relative to the at least one inert gas is from 0.05 to 0.3 molar percent.

13. (Original) The method according to claim 1, wherein step (ii) is carried out at a reaction temperature from 300 to 500° C.

14. (Original) The method according to claim 13, wherein step (ii) is carried out at a reaction temperature from 350 to 450° C.

15. (Currently Amended) The method according to claim 13, wherein the metal film of step (i) is heated rapidly from a first temperature to a reaction temperature of between 300 to 500° C. within 5 minutes.

16. (Original) The method according to claim 1, wherein during step (ii) the metal film of step (i) is exposed to the source of VIA₁ for a period from 10 to 120 minutes.

17. (Original) The method according to claim 16, wherein the metal film of step (i) is exposed to the source of VIA₁ for a period from 30 to 60 minutes.

18. (Original) The method according to claim 1, wherein the first film of-step (ii) has below 50 atomic % of the VIA₁ element.

19. (Original) The method according to claim 8, wherein the first film of step (ii) has below 50 atomic % of Se.

20. (Currently Amended) The method according to claim 1, wherein the first film of step (ii) is treated under conditions ~~to ensure~~ such that the mixture of the at least one binary alloy and the at least one group IB-III_A-VI_{A1} ternary alloy remains stable.

21. (Original) The method according to claim 20, wherein the source of the VI_{A1} element is removed so as to maintain the stability of the mixture.

22. (Original) The method according to claim 20, wherein the first film of step (ii) is exposed to an inert atmosphere for 5 to 20 minutes.

23. (Original) The method according to claim 20, wherein the first film of step (ii) is cooled to temperatures below 200° C.

24. (Original) The method according to claim 5, wherein the first film of step (ii) comprises a mixture of at least one binary alloy selected from the group consisting of InSe, CuSe and Ga₂Se₃ and at least one ternary alloy selected from the group consisting of CuInSe₂ and CuGaSe₂, where VI_{A1} is Se.

25. (Currently Amended) The method according to claim 1 which is for producing a group IB-III_A-VI_A pentenary alloy semiconductor film, and wherein:

step (i) comprises providing a metal film including a mixture of at least one group IB element, a first group III_A element, ~~[[()]]~~ the first group III_A element hereinafter being referred to as III_{A1}~~[[()]]~~ and a second group III_A element, ~~[[()]]~~ the second group III_A element hereinafter being referred to as III_{A2}~~[[()]]~~;

step (ii) comprises heat treating the metal film of step (i) in the presence of a source of VI_{A1} under such conditions ~~to form~~ that the reaction between the group VI_{A1} element and the metals of the mixture of the metal film is incomplete and a first film is formed comprising a mixture of binary alloys selected from the group consisting of a group IB-VI_{A1} alloy, a group III_{A1}-VI_{A1} alloy and a group III_{A2}-VI_{A1} alloy and two ternary alloys, namely a group IB-III_{A1}-VI_{A1} alloy and a group IB-III_{A2}-VI_{A1} alloy;

step (iii) comprises heat treating the first film of step (ii) in the presence of a source of VI_{A2} under conditions to convert the first film of step (ii) into a second film comprising at least one alloy selected from the group consisting of a group IB-VI_{A1}-VI_{A2} alloy, a group III_{A1}-VI_{A1}-VI_{A2} and a group III_{A2}-VI_{A1}-VI_{A2} alloy; and the ternary alloys of step (ii); and

step (iv) comprises heat treating the second film of step (iii) to form a group IB-III_{A1}-III_{A2}-VIA₁-VIA₂ pentenary alloy semiconductor film.

26. (Original) The method of claim 25, wherein the first film of step (ii) includes a mixture of binary alloys in the form of a group IB-VIA₁ alloy, a group III_{A1}-VIA₁ alloy and a group III_{A2}-VIA₁ alloy and ternary alloys in the form of a group IB-III_{A1}-VIA₁ alloy and a group IB-III_{A2}-VIA₁ alloy and wherein the second film of step (iii) includes a mixture of alloys in the form of a group IB-VIA₁-VIA₂ alloy, a group III_{A1}-VIA₁-VIA₂ and a group III_{A2}-VIA₁-VIA₂ alloy and the ternary alloys of step (ii).

27. (Currently Amended) The method according to claim 26, wherein step (iv) comprises a first heat treatment step wherein the second film of step (iii) is heated to form a third film comprising a mixture of quaternary alloys selected from the group consisting of a group IB-III_{A1}-VIA₁-VIA₂ alloy and a group IB-III_{A2}-VIA₁-VIA₂ alloy; and then subjecting the third film to a second heat treatment step wherein the third film is annealed ~~so as to~~ thereby forming a group IB-III_{A1}-III_{A2}-VIA₁-VIA₂ pentenary alloy semiconductor film.

28. (Currently Amended) The method according to claim 27, wherein the first heat treatment step of step (iv) comprises heating the second film of step (iii) in the presence of a source of VIA₂ ~~so as to~~ thereby forming the third film.

29. (Original) The method according to claim 28, wherein the second film of step (iii) is exposed to the source of VIA₂ for a period of from 5 to 10 minutes.

30. (Currently Amended) The method according to claim 29, wherein the first heat treatment step of step (iv) comprises heating the second film of step (iii) at a temperature from 450 to 600° C. ~~so as to~~ thereby forming the third film.

31. (Original) The method according to claim 30, wherein the first heat treatment step of step (iv) comprises heating the second film of step (iii) at a temperature from 500 to 550° C.

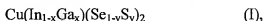
32. (Original) The method according to claim 27, wherein the second heat treatment step of step (iv) comprises annealing the third film for 15 to 90 minutes.

33. (Original) The method according to claim 32, wherein the second heat treatment step of step (iv) comprises annealing the third film at a temperature from 500° C. to 600° C.

34. (Original) The method according to claim 33, wherein the second heat treatment step of step (iv) comprises annealing the third film at a temperature from 520° C. to 580° C.

35. (Original) The method according to either one of claims 26 and 27, wherein IB is Cu, IIIA₁ is In, IIIA₂ is Ga, VIA₁ is Se and VIA₂ is S.

36. (Currently Amended) The method according to claim [[35]] 27, wherein IB is Cu, IIIA₁ is In, IIIA₂ is Ga, VIA₁ is Se and VIA₂ is S, wherein the second heat treatment step of step (iv) comprises annealing the third film under conditions so as to form a pentenary alloy having the general formula I:



wherein x and y are smaller than 1, provided that x and y independently cannot be equal to zero at the same time.

37. (Original) The method according to claim 35, wherein a source of S is a gaseous mixture of H₂S and at least one inert gas.

38. (Original) The method according to claim 37, wherein the molar concentration of S relative to the at least one inert gas is from 0.1 to 10 molar percent.

39. (Original) The method according to claim 38, wherein the molar concentration of S relative to the at least one inert gas is from 0.3 to 0.5 molar percent.

40. (Original) The method according to claim 25, wherein, in step (iii), the first film of step (ii) is heat-treated at a temperature of from 100 to 500° C.

41. (Original) The method according to claim 40, wherein, in step (iii), the first film of step (ii) is heat-treated at a temperature of 450° C.

42. (Original) The method according to claim 40, wherein, in step (iii), the first film of step (ii) is heat-treated for a period of from 5 to 10 minutes.

43. (Currently Amended) The method according to claim 25 which is for producing a group IB-III A-VIA alloy semiconductor film, and wherein

step (i) comprises providing a metal film comprising a mixture of Cu, In and Ga;

step (ii) comprises heat treating the metal film in the presence of a gaseous mixture of H₂Se and at least one inert gas, wherein the molar concentration of Se relative to the at least one inert gas is from 0.05 to 0.3%, at a temperature of from 350° C. to 450° C., for a period of between 30 to 60 minutes, thereby so as to forming a first film comprising a mixture of binary alloys in the form of CuSe, InSe, Ga₂Se₃ and the ternary alloys, namely CuInSe₂ and CuGaSe₂;

step (iii) comprises heat treating the first film of step (ii) in the presence of a gaseous mixture of H_2S and at least one inert gas, at a temperature from $400^\circ C.$ to $500^\circ C.$, for a period from 5 to 10 minutes, ~~so as to~~ thereby forming a second film comprising a mixture of sulfoselenides in the form of $Cu(Se,S)$, $In(Se,S)$ and $Ga(Se,S)$ and the ternary alloys of step (ii); and

step (iv) comprises heat treating the second film of step (ii) in the presence of H_2S in Ar, at a temperature of from $500^\circ C.$ to $550^\circ C.$, for 5 to 10 minutes such that the sulfoselenides react with the ternary alloys of step (ii) to form a third film comprising a mixture of $CuIn(Se,S)_2$ and $CuGa(Se,S)_2$, and subsequently annealing the mixture of $CuIn(Se,S)_2$ and $CuGa(Se,S)_2$ at a temperature of from $520^\circ C.$ to $580^\circ C.$ ~~so as to~~ thereby forming a pentenary alloy having the general formula (I)



wherein x varies from 0.1 to 0.5 and y varies from 0.05 to 0.8.

44. (Currently Amended) A method for producing a group IB-III_A-VIA quaternary alloy semiconductor film, the method comprising the steps of:

(i) providing a metal film comprising a mixture of at least one group IB element, a first group III_A element, the first group III_A element hereinafter being referred to as III_{A1}, and a second group III_A element, the second group III_A element hereinafter being referred to as III_{A2} and group III_A metals;

(ii) heat treating the metal film in the presence of a source of a first group VIA element, [[([)] said first group VIA element being hereinafter referred to as VIA₁[[)]] under such conditions to form that the reaction between the group VIA₁ element and the metals of the mixture of the metal film is incomplete and a first film is formed comprising a mixture of at least one binary alloy selected from the group consisting of a group IB-VIA₁ alloy and a group III_A-VIA₁ alloy; and at least one group IB-III_A-VIA₁ ternary alloy, wherein the mixture is a stable mixture such that the molar ratio of all the group IB-VIA₁ and/or group III_A-VIA₁ alloys to the at least one group IB-III_A-VIA₁ ternary alloy remains substantially constant, and

(iv) heat treating the first film of step (ii) to form a group IB-III_A-VIA quaternary alloy semiconductor film.

45. (Original) The method according to claim 44, wherein the first film of step (ii) is treated under conditions to ensure that the mixture of the at least one binary alloy and the at least one group IB-III A-VIA₁ ternary alloy remains stable.

46. (Currently Amended) The method according to claim 45, wherein the source of the VIA₁ element is removed so as to thereby maintaining the stability of the mixture.

47. (Original) The method according to claim 45, wherein the first film of step (ii) is exposed to an inert atmosphere for 5 to 20 minutes.

48. (Original) The method according to claim 45, wherein the first film of step (ii) is cooled to temperatures below 200° C.

49. (Currently Amended) The method according to claim 44, wherein the metal film of step (i) is provided on a substrate ~~optionally coated with a metal layer~~.

50. (Currently Amended) The method according to claim 49, wherein the substrate is coated with metal layer is a Mo layer.

51. (Original) The method according to claim 44, wherein the metal film of step (i) comprises a mixture of metals selected from the group consisting of Cu, In and Ga.

52. (Original) The method according to claim 51, wherein the metal film of step (i) is a Cu—In—Ga alloy metal film.

53. (Canceled)

54. (Original) The method according to claim 44, wherein the group VIA₁ element is Se.

55. (Original) The method according to claim 44, wherein a source of the group VIA₁ element is a gaseous mixture of H₂Se and at least one inert gas.

56. (Original) The method according to claim 55, wherein the inert gas is Ar.

57. (Original) The method according to claim 55, wherein the molar concentration of Se relative to the at least one inert gas is from 0.01 to 15 molar percent.

58. (Original) The method according to claim 57, wherein the molar concentration of Se relative to the at least one inert gas is from 0.05 to 0.3 molar percent.

59. (Original) The method according to claim 44, wherein step (ii) is carried out at a reaction temperature from 300 to 500° C.

60. (Original) The method according to claim 59, wherein step (ii) is carried out at a reaction temperature from 350 to 450° C.

61. (Original) The method according to claim 59, wherein the metal film of step (i) is heated rapidly to a reaction temperature of between 300 to 500° C. within 5 minutes.

62. (Original) The method according to claim 44, wherein during step (ii) the metal film of step (i) is exposed to the source of VIA₁ for a period from 10 to 120 minutes.

63. (Original) The method according to claim 62, wherein the metal film of step (i) is exposed to the source of VIA₁ for a period from 30 to 60 minutes.

64. (Original) The method according to claim 44, wherein the first film of step (ii) has below 50 atomic % of the VIA₁ element.

65. (Original) The method according to claim 54, wherein the first film of step (ii) has below 50 atomic % of Se.

66. (Original) The method according to claim 44, wherein the first film of step (ii) comprises a mixture of at least one binary alloy selected from the group consisting of InSe, CuSe and Ga₂Se₃ and at least one ternary alloy selected from the group consisting of CuInSe₂ and CuGaSe₂, where VIA₁ is Se.

67. (Currently Amended) The method according to claim 44 which is for producing a group IB-III_A-VIA quaternary alloy semiconductor film, and wherein:

step (i) comprises providing a metal film including a mixture of at least one group IB element, a first group III_A element, [(I)] the first group III_A element hereinafter being referred to as III_{A1}[(I)] and a second group III_A element, [(I)] the second group III_A element hereinafter being referred to as III_{A2}[(I)];

step (ii) comprises heat treating the metal film of step (i) in the presence of a source of VIA₁ under such conditions to form that the reaction between the group VIA₁ element and the metals of the mixture of the metal film is incomplete and a first film is forming comprising a mixture of binary alloys selected from the group consisting of a group IB-VIA₁ alloy, a group III_{A1}-VIA₁ alloy and a group III_{A2}-VIA₁ alloy and a ternary alloy being a group IB-III_{A1}-VIA₁ alloy;

step (iv) comprises heat treating the first film of step (ii) to form a group IB-III_{A1}-III_{A2}-VIA₁ quaternary alloy semiconductor film.

68. (Original) The method according to claim 67, wherein the heat treatment of step (ii) is carried out at a reaction temperature of 400° C.

69. (Currently Amended) The method according to claim 67, wherein step (iv) comprises a first heat treatment step wherein the first film of step (ii) is heated and then subsequently a second heat treatment step wherein the first film is annealed thereby so as to forming a group IB-III_{A1}-III_{A2}-VI_{A1} quaternary alloy semiconductor film.

70. (Original) The method according to claim 69, wherein the first heat treatment step of step (iv) comprises heating the first film of step (ii) to a reaction temperature of from 100 to 600° C.

71. (Original) The method according to claim 69, wherein the second heat treatment step of step (iv) comprises first annealing the first film of step (ii) in the presence of an inert gas and then subsequently annealing the first film in the presence of a source of VI_{A1}.

72. (Original) The method according to claim 71, wherein the first film of step (ii) is first annealed in the presence of the inert gas at a temperature of from 100 to 600° C.

73. (Original) The method according to claim 72, wherein the first film of step (ii) is first annealed in the presence of the inert gas at a temperature of from 500 to 550° C.

74. (Original) The method according to claim 72, wherein the first film is first annealed in the presence of the inert gas for a period of from 10 to 60 minutes.

75. (Original) The method according to claim 71, wherein the first film of step (ii) is subsequently annealed in the presence of a source of VI_{A1} for at least 30 minutes.

76. (Original) The method according to claim 75, wherein the first film of step (ii) is annealed in the presence of a source of VI_{A1} at a temperature of 500° C.

77. (Original) The method according to either one of claims 67 and 69, wherein IB is Cu, III_{A1} is In, III_{A2} is Ga, VI_{A1} is Se.

78. (Currently Amended) The method according to claim 77, wherein the quaternary alloy has a formula (II)



wherein x may vary from 0.25 to 3.0.

79. (Original) The method according to claim 77, wherein a source of Se is a gaseous mixture of H₂Se and at least one inert gas.

80. (Original) The method according to claim 79, wherein the molar concentration of Se relative to the at least one inert gas is 0.12%.

81. (Currently Amended) The method according to claim 67 which is for producing a group IB-III_A-VI_A quaternary alloy semiconductor film, and wherein:

step (i) comprises providing a metal film comprising a mixture of Cu, In and Ga in elemental or alloy form;

step (ii) comprises heat treating the metal film in the presence of a gaseous mixture of H₂Se and at least one inert gas, wherein the molar concentration of Se relative to the at least one inert gas is from 0.05 to 0.3%, at a temperature of 400° C., for a period of between 30 to 60 minutes, so as to form a mixture of binary alloys in the form of CuSe, InSe, Ga₂Se₃ and a ternary alloy in the form of a CuInSe₂ alloy.

step (iv) comprises subjecting the first film of step (ii) to the following consecutive steps:

a first heat treatment step comprising heat treating the first film of step (ii) to a reaction temperature from 500° C. to 550° C. in 15 to 30 minutes;

a second heat treatment step comprising first annealing the first film of step (ii) in Ar(g) at a reaction temperature from 500° C. to 550° C. for at least 15 minutes; and then secondly annealing the first film of step (ii) in the presence of a gaseous mixture of H₂Se and Ar(g), wherein the molar concentration of Se relative to Ar is 0.12% ~~so as to thereby forming a~~ quaternary alloy having the general formula (II)



wherein x may vary from 0.25 to 3.0.

82. (Currently Amended) A ~~[[The]]~~ method according to claim 44, which is for producing a group IB-III_A-VI_A quaternary alloy semiconductor ~~[[:]]~~ film, and wherein the method comprising:

step (i): ~~comprises~~ providing a metal film including a mixture of at least one group IB element and a group III_A element;

step (ii): ~~comprises~~ heat treating the metal film of step (i) in the presence of a source of VI_{A1} under such conditions to form that the reaction between the group VI_{A1} element and the metals of the mixture of the metal film is incomplete and a first film is formed comprising a mixture of binary alloys selected from the group consisting of a

group IB-VIA₁ alloy, a group IIIA-VIA₁, and a ternary alloy being a group IB-IIIA-VIA₁ alloy; and

step (iv) comprises heat treating the first film of step (ii) in the presence of a source of VIA₂ so -as to form a group IB-IIIA-VIA₁-VIA₂ quaternary alloy semiconductor film.

83. (Currently Amended) The method according to claim 82, wherein step (iv) comprises a first heat treatment step wherein the first film of step (ii) is heated and then subsequently a second heat treatment step wherein the first film of step (ii) is annealed thereby so as to forming a group IB-IIIA-VIA₁-VIA₂ quaternary alloy.

84. (Original) The method according to claim 83, wherein the first heat treatment step of step (iv) comprises heating the first film of step (ii) to a reaction temperature from 100 to 600° C.

85. (Original) The method according to claim 83, wherein the second heat treatment step of step (iv) comprises annealing the first film of step (ii) in the presence of a source of VIA₂.

86. (Original) The method according to claim 85, wherein the first film of step (ii) is annealed in the presence of the source of VIA₂ at a temperature from 100 to 600° C.

87. (Original) The method according to claim 86, wherein the first film of step (ii) is annealed in the presence of the source of VIA₂ at a temperature from 500 to 550° C.

88. (Original) The method according to claim 87, wherein the first film of step (ii) is annealed in the presence of a source of VIA₂, at a temperature of 500° C.

89. (Original) The method according to claim 85, wherein the first film of step (ii) is annealed in the presence of a source of VIA₂ for at least 30 minutes.

90. (Original) The method according to either one of claims 82 and 83, wherein IB is Cu, the group IIIA element is In, VIA₁ is Se, VIA₂ is S.

91. (Currently Amended) The method according to claim 90, wherein the quaternary alloy has a formula (III);



wherein y may vary from 0.1 to 0.5.

92. (Original) The method according to claim 90, wherein a source of S is a gaseous mixture of H₂S and at least one inert gas.

93. (Original) The method according to claim 92, wherein the molar concentration of S relative to the at least one inert gas is 0.35 molar percent.

94. (Currently Amended) The method according to claim 82, which is for producing a group IB-III-A-VIA quaternary alloy semiconductor film, and wherein:

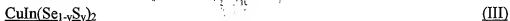
step (i) comprises providing a metal film comprising a mixture of Cu and In in elemental or alloy form;

step (ii) comprises heat treating the metal film in the presence of a gaseous mixture of H_2Se and at least one inert gas, wherein the molar concentration of Se relative to the at least one inert gas is from 0.05 to 0.3% for a period of between 30 to 60 minutes, so as to thereby forming a mixture of binary alloys in the form of $CuSe$ and $InSe$ and a ternary alloy, namely $CuInSe_2$; and

step (iv) comprises subjecting the first film of step (ii) to the following consecutive steps:

a first heat treatment step comprising heat treating the first film of step (ii) to a reaction temperature from $500^\circ C.$ to $550^\circ C.$ in 15 to 30 minutes;

a second heat treatment step comprising annealing the first film of step (ii) in the presence of a gaseous mixture of H_2S and $Ar(g)$, at a temperature of from $500^\circ C.$ to $550^\circ C.$, wherein the molar concentration of S relative to Ar is 0.35% so as to thereby forming a quaternary alloy having the general formula (III)



wherein y may vary from 0.1 to 0.5.

95. (New) The method according to claim 1, wherein the IB-III-A-VIA quaternary or higher alloy semiconductor film is substantially homogenous.

96. (New) The method according to claim 44, wherein the IB-III-A-VIA quaternary alloy semiconductor film is substantially homogenous.

97. (New) The method according to claim 82, wherein the IB-III-A-VIA quaternary alloy semiconductor film is substantially homogenous.

98. (New) The method of Claim 36, wherein x varies from 0.1 to 0.5.

99. (New) The method of Claim 36, wherein x varies from 0.25 to 0.3.

100. (New) The method of Claim 36, wherein y varies from 0.05 to 0.8.